THE USE OF MUNICIPAL WASTE AS FUEL

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Staff Report

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Preface

The following report has been prepared at the request of the Renewable Resources Study Group of the public advisory committees to the Environment Council of Alberta. The Study Group requested a summary of literature on the use of municipal wastes as fuel for power generation. The topic has been enlarged to include some other options which involve separation and processing of usable elements in municipal wastes, so that the relative merits of power generation from wastes might be evident.

The report also describes some issues that were identified in the literature as relevant to discussions of landfilling versus energy and resource recovery options. Since there are no energy recovery operations in Alberta, and few in Canada, the issues described are based primarily on experiences in Great Britain and the United States. The same issues would probably surface in discussions about alternatives to landfilling in Alberta.

Since the report is intended as a summary, some of the information in the report is generalized. Readers who are interested in more details may consult the references which were used in the preparation of this report.

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Why Examine Alternatives to Landfilling?

For many people, landfilling is no longer acceptable as the sole method of solid waste disposal. Separation and processing of usable elements within a solid waste stream (that is, resource recovery) with subsequent disposal of the unusable elements to landfills is a feasible alternative in many circumstances. In the long term, conservation of energy and materials should be the main reason for resource recovery. Energy is saved because separation and reprocessing of some substances within the waste stream consumes less energy than manufacturing the substances from raw materials.[1,2] Aluminum, for instance, can be recycled using only about 5 percent of the energy needed to manufacture it from aluminum ore.[3] Energy is also conserved when heat is recovered from incinerable wastes. While only a small fraction of the total energy needs of a country can be derived from the combustible solid wastes – for example, about 2 percent in the United States and the United Kingdom[4,5] – over time the recovered energy would represent a positive contribution to a country's total energy budget. Energy recovery is especially warranted if the energy recoverable by burning the waste exceeds that spent in making energy recovery possible; that is, if the energy is available at a net energy profit.

For the present, however, the conservation ethic ranks behind economic and specific environmental concerns as the main reasons for interest in resource and energy recovery. Landfilling is becoming more costly and more difficult, particularly when, prior to landfilling, the few suitable landfill sites are privately owned;[6] because of increasing transportation costs resulting from landfills that are increasingly distant from the centres generating the waste;[7] and because of environmental regulations for landfill sites.[8] Some of the increased costs for acquiring and operating landfill sites have stemmed from public concern about the safety of landfill sites. Landfills have long been regarded as unhealthy, unsightly, and unpleasant to be near.[1] There is public concern about the leaching of products of decomposition (and toxic substances where hazardous wastes are landfilled) into nearby groundwater and soil; special precautions such as lining sanitary landfills with plastic or clay may not eliminate long-term problems with leaching.

At present, the conservation ethic ranks behind economic and specific environmental concerns as the main reasons for interest in resource and energy recovery.

Landfills can be reclaimed, most often for recreational use. In recent public meetings regarding the siting of a new landfill for the city of Edmonton, the consensus expressed was to use old gravel pits in the North Saskatchewan River valley for landfilling so that eventually the covered landfill would provide more opportunities for river valley recreation.[9] The concerns many people have with environmental problems of landfilling, however, are probably great enough to discount the provision of recreational space as an advantage associated with landfilling.

Advantages and Disadvantages of Some of the Alternatives to Landfilling

Incineration

Incineration is a common alternative to landfilling where there is insufficient landfill capacity close to the waste generators.[10] One of the main advantages of incineration is extension of the lifetime of landfill sites because of the reduction in the volume of the waste stream. The ash of incinerated waste is much less bulky than incinerable waste. Since final landfill volumes when incinerating may be less than one-half the final landfill volumes when using sanitary landfills (Table 1), lifetimes of landfill sites may be at least doubled. Heat recovery, moreover, is often possible once an incineration system is in place. Not only is there a potential to save on conventional fuels; there is a potential to recover some of the costs of incineration by selling the heat or converting it to electricity.

There is much energy to be derived from municipal waste streams. The amount of energy which can be recovered depends upon content, location, source, and season, but generally speaking the following data are typical:

1) The calorific value of municipal waste is significant. Typical crude refuse in the United Kingdom has a calorific value of 9,000 - 11,000 kJ/kg (3,960-4,840 BTUs per pound) which is between 36 and 40 percent of the calorific value of United Kingdom industrial coal.[11] Klumb and Hollander[12] derived a heating value of 9,300-16,280 kJ/kg (4,000-7,000 BTUs per pound) for a generalized mix of household, commerical, institutional, and industrial wastes in the United States.

2) The calorific value of the municipal waste stream is increasing because of the increasing amount of paper and plastic in the stream.[13]

In some places, significant reductions in the use of hydrocarbon fuels are possible by using the solid wastes as fuel, but processing (for example, separation, shredding, pelletizing) of the solid waste stream before burning is often necessary because very few installations can burn as-received refuse. The processing almost invariably results in greater costs and a decrease in net energy,[14] the latter because the energy expended in processing subtracts from the energy gained by burning the waste. There are, however, benefits to be derived from this processing including mitigation of some technical problems associated with mass burning*, better adaptability of waste fuels to existing hydrocarbon burning units, easier transport and storage of fuel, and higher thermal efficiency; that is, ability to extract more of the combustion energy as steam.[14]

Municipal waste can be burned with or without hydrocarbon fuels; burning municipal waste without hydrocarbon fuels is the more common alternative in North America.[9] When refuse is burned with other hydrocarbons (typically coal) and the derived heat is used, the process is known as "co-generation."

*Mass burning – incineration with heat recovery

Table 1. Reduction in Volume of Landfilled Materials: Comparison Between Sanitary Landfilling and Conventional Incineration

	Original Volume as Fractions	Reduction Factor	Final Volume of Landfilled Materials as Fraction of Original Volume
Sanitary Landfill			
Incinerable Waste*	0.8	0.166	0.133
Bulky and Non-incinerable Waste	0.2	0.5	0.100
	1.0		0.233
Conventional Incineration			
Incinerable Waste*	0.8	0.0145	0.012
Bulky and Non-incinerable Waste	0.2	0.5	0.100
	1.0		0.112

Source: After Weinstein and Toro 1976:3.

*Bulk density assumed to be 89 kilograms/cubic metre (150 pounds/cubic yard).

Note: The final volume of landfilled material resulting from incineration is approximately 48 percent of the final landfill volume resulting from sanitary landfilling.

There are several technological and environmental problems associated with refuse and refuse-coal combustion systems. Corrosion is one of the main technological problems. The amount of corrosion strongly depends upon the operating conditions of the boiler.[15] The increased corrosion when burning refuse is in part due to the heterogeneity in physical form and composition of refuse.[16]

Heterogeneity in the physical form of refuse makes the distribution of combustion air difficult, and if the air is improperly distributed the combustion gases may be chemically reducing which leads to corrosion of hot steel surfaces.[16] Shifts to excess oxidative conditions can also result in high metal wastage[16] and reduce the efficiency of the boiler compared to 100 percent coal-fired units.[17] The heterogeneity in chemical composition is due to the different types of incinerable refuse such as paper, plastics, and food wastes typically found in waste streams. In addition, the chemical heterogeneity between refuse and coal enhances corrosion. For example, in comparison to coals, refuse often has higher percentages of potassium and sodium compounds. These compounds can contribute to corrosion and to the formation of slag deposits on heat exchange surfaces.

The slag deposits can be corrosive in themselves and may trap other corrosive compounds.[16] Reduction in the heterogeneity of refuse, so that optimum operating conditions for the boiler can be maintained and corrosion problems can be minimized, is one of the main reasons why refuse is processed into some type of refuse-derived fuel.[18] When refuse-derived fuels make up 10-20 percent of the boiler heat input,[18, 19] and if particle size of the refuse-derived fuel is similar to that of the coal,[20] corrosion problems are minimal.

Another technological problem is that burning refuse with conventional fuels requires some furnace redesign, such as in the feed mechanisms. The degree of modification depends upon the form of the refuse and the means by which combustion is effected. For example, where refuse is being co-fired with coal, few changes in the feed mechanisms of the boilers are likely to be necessary if dust (finely pulverized) refuse-derived fuels are used,[21] whereas more extensive changes to the boiler would be required if unsorted, unshredded refuse were to be incinerated. Low grades of refuse fuels, however, may be quite usable if a process known as fluidized-bed combustion is used for the recovery of energy from waste.[22]

The general consensus regarding the redesign of coal boilers to incinerate refuse is that when the refuse is a small percentage of fuel input and when it is of similar size to the main fuel, the need for redesign is minimal.[20, 23] Modest redesign of furnaces can increase the tolerance for refuse to 25-30 percent of total fuel input, but beyond that level major redesign is necessary.[20] Major redesign of oil- and gas-fired boilers is necessary to burn refuse because they have no ash-handling capacity. The costs of redesigning oil- and gas-fired boilers are very high.

Incineration and its variants are not without consequence to air quality. In many (but not all) ways co-generation appears to be preferable to burning refuse or coal alone. Ananth et al.[24] briefly described pollution tests for a mass-burn refuse incinerator in Braintree, Massachusetts. The tests showed low emissions of sulphur oxides, nitrogen oxides, and hydrocarbons. On the other hand, carbon monoxide levels were inexplicably high, and in initial tests particulate matter exceeded federal and state regulations. Levels of chlorides, sulphates, and some trace metals in the fly ash from the incinerator that could be of concern were found. The fly ash did not contain detectable levels of polychlorinated biphenyls (PCBs), but did contain four polycyclic aromatic hydrocarbons (PAHs.) (Some polycyclic aromatic hydrocarbons are suspected cancer-causing agents.)

In many ways (but not all) co-generation appears to be preferable to burning refuse or coal alone.

Captured fly ash could be disposed of in landfills (where prevention of unacceptable leaching should be an element of landfill design); if a hazardous waste facility were available, the fly ash could be pretreated prior to disposal in a landfill. Fly ash (and the undesirable chemicals it contains) not captured would be dispersed in the atmosphere.

Co-generation seems to result in fewer particulate emissions than incineration[25, 26] "because of separation of inorganic materials from the combustibles, and efficient electrostatic precipitators on the boiler";[26] in the United States the particulate emission standards are less stringent for new incinerators than they are for new co-generation facilities burning more than 250 million BTUs of fossil fuel per hour.[27]

Comparisons between co-generation and coal-fired boilers have shown a trend toward lower levels of sulphur dioxide in the co-generation boilers because the sulphur content of refuse is less than that of most coals, but higher levels of chlorides because of the presence of polyvinyl chlorides (plastics) in the refuse stream. There is also a tendency for lower nitrogen oxide and carbon monoxide levels with co-generation, but this may not be the direct result of burning refuse since the levels of both compounds are highly dependent upon boiler combustion conditions.[28] Compared to coal-firing, co-generation results in increased emissions of trace metals, notably lead.[28, 29] Abert and Alter[29] conceded that "it is difficult to assess the health significance of increased lead emissions," but estimated that the highest possible ground level concentrations would be about 20 percent of the Environmental Protection Agency's standards.

Boilers with the capacity to burn significant amounts of refuse-derived fuel would probably have to be equipped with electrostatic precipitators,[30] or if coal boilers were previously equipped with electrostatic precipitators, the precipitators might have to be modified.[31] (In the United States, when modifications of old boilers to burn refuse in conjunction with fossil fuels were first made, the modified boilers did not have to comply with new source standards.[32] Shannon et al.,[33] in tests at the St. Louis-Union Electric demonstration plant, noted a decrease in the electrostatic precipitator efficiency when coal and refuse were fired together. The decrease in efficiency was caused by increased gas flow rates resulting from changes in the fuel composition and moisture content and changes in the precipitator's performance characteristics.[33, 34] The higher ash content of refuse-derived fuel and its lower sulphur content have also been implicated in decreased electrostatic precipitator performance.[18] There is some evidence that "where relatively low-sulphur coal is being fired with exit flue gas temperatures greater than about 270-280° F, the addition of low-sulphur refuse may introduce, or make worse, resistivity problems within the precipitator due to the lack of sufficient sulphur trioxide conditioning agent naturally present from the coal sulphur."[31] Klumb and Hollander[18] estimated that a reduction of 0.25 to 1.0 percent in precipitator efficiency could be expected when firing refuse-derived fuel with coal. Without some modifications to improve the performance of electrostatic precipitators, such as changing the operating conditions of the boilers by conditioning the gas with sulphur trioxide or similar alternatives,[31] it is conceivable that overall air pollution could be worse when firing refuse with coal than when firing coal alone. Under some circumstances increasing the sulphur content of refuse may reduce corrosion in addition to improving electrostatic precipitator performance.[35]

Incineration and its variants may detrimentally affect more than just the air. If scrubbers are used to decrease the emissions of stack pollutants, some water pollution may result.[36, 37, 38] The main effect of refuse-derived fuel combustion, however, is through the sluice water which carries bottom ash from the boiler; in one test, compared to firing coal only "co-firing increased the ash pond effluent concentrations of BOD [*sic*] and suspended solids [and] reduced dissolved oxygen concentrations..."[29] because refuse makes more ash than coal. Heavy truck traffic associated with larger resource recovery fuel plants may be a negative environmental impact in a local area if there is insufficient attention paid to routing.[39] Heavy truck traffic is also common with landfills, but the traffic may not be as significant a problem as it is with recovery plants because landfills, more so than resource recovery plants, tend to be located in rural areas.

There are many variants of incineration, and alternatives to incineration, which make use of municipal solid wastes. Following are brief comments on unique advantages and disadvantages of some of the variants and alternatives, divided into two main categories:

1) Using heat generated by incineration
   i) district heating
   ii) industrial use
   iii) generation of electricity

2) Alternatives to incineration
   i) refuse-derived fuel
   ii) recycling

This separation into two main categories is not meant to imply that the two categories are incompatible elements of a refuse treatment program, for any of the variants and alternatives can complement another. For example, refuse-derived fuels are ultimately incinerated and heat recovery may be practised, but refuse-derived fuel has been placed under the second alternative because it is a step removed from incineration and because the municipal authority is often responsible for the manufacture of the fuel but not its incineration.

Using Heat Generated By Incineration

District Heating

Heat generated by refuse incineration can be transferred for district heating by hot water or steam. District heating through incineration of refuse would be very costly in areas where no provision currently exists for distribution of the steam. Some marketing problems exist because steam cannot be stored,[40] and because there are wide variations in demand for such heat between winter and summer.[41] To circumvent the marketing problem the municipal solid wastes incinerator may be sized to provide the base load only, with back-up systems to provide peak demands, or processing the combustible refuse into pellets may allow the refuse to be stored in order to meet the higher winter demands.[41]

Industrial Use

Some of the problems of large seasonal variations in demand for heat or for fuel associated with district heating may be avoided by using industrial markets where demand is more uniform and therefore more satisfactory for incinerator operations.[42] Attractive features of having industrial users burn processed municipal solid wastes in their solid fuel boilers include:

1) Because new incinerators would not have to be constructed, less capital investment is required by the municipality.[43]

2) Because industrial users may purchase their conventional fuel in smaller volumes, they could conceivably pay more for processed refuse than do large industries such as utilities which buy their fuels in larger and cheaper-per-unit quantities; the higher price paid would improve the ability of energy from municipal solid waste to compete with conventional fuels.[44] Finding a large enough industrial market for all the refuse, however, may be difficult because it would probably take several industrial users to consume the same amount of power as a large consumer such as an electric utility company or a heating district.

The use of municipal solid wastes in conjunction with conventional fuels to fuel cement kilns may be particularly promising.[45, 46] For example, the Blue Circle Shoreham works in the United Kingdom injected up to 100,000 metric tons of pulverized and prepared waste per year into cement kilns, allowing a substantial reduction in coal use.[45] There are several advantages to using wastes for fuel in cement kilns:

1) Kilns have large and high-temperature combustion chambers capable of completely destroying odoriferous and toxic organic compounds.[46]

2) The alkalinity of the cement raw materials is capable of neutralizing acid gases.[46, 47]

3) Ash produced from the refuse is incorporated into the cement without harm.[47]

4) Kilns are fitted with efficient systems for removing particulates.[46, 47]

The process depends upon refuse that has a high paper content and refuse that has been densified.[22]

Generation of Electricity

Steam generated by incineration of refuse can be used to drive electric generators. Some of the problems of using steam for electricity generation are the same as using steam for district heating, for example, those problems of matching supply with demand when the boiler is 100 percent fired with solid waste.[48] To some extent the problem of matching supply with demand is overcome if the electricity is fed into a power grid. Additional deterrents include inefficient generation of electricity at the low pressures of steam normally produced and problems in producing high-pressure, high-temperature steam in solid waste incinerators[49] because solid waste does not have as high a calorific value as fossil fuels. Like industrial use of refuse, electricity generation offers advantages of better load pro-

files and better levels of utilization than conventional heat consumers[43] such as district heating. MacAdam[50] identifies other advantages of electricity generation over industrial use or district heating, including:

1) Simplification of siting problems because connection to a power grid can occur at several locations. Such is not the case in district heating where economics dictates that the incinerator be sited adjacent to the steam user. Because the power plant can be sited close to the refuse source, connecting the refuse-generated electricity into a grid may be less costly than the fuel storage and transportation costs for bulk fuels associated with landfills or power plants distant from urban refuse generators.[51, 52]

2) Reduced costs for the municipal authority because there would be no need to have back-up generating facilities (if the authority is not the utility). The back-up generating facilities would not be required since refuse-generated electricity is usually a small fraction of a utility company's generating capacity. Back-up facilities would likely be required if refuse were incinerated for district heating.

3) Operational simplicity because trying to match steam temperatures and pressures with those specific to various industrial users is more difficult than trying to optimize steam conditions for electricity generation at one or two power plants.

It is estimated that there is enough combustible refuse in the United States to generate up to 8 percent of its electricity needs.

In some parts of the world there is enough refuse to generate a significant portion of the area's electricity needs. For example, refuse-generated electricity supplies 6 percent of Amsterdam's electricity needs, and it is estimated that there is enough combustible refuse in the United States to generate up to 8 percent of its electricity needs.[38]

In contrast to the above examples, it appears that little power can be generated from refuse in Edmonton. Edmonton Water and Sanitation estimated that if Edmonton's entire waste stream were processed into fuel, 30 megawatts of net power could be generated. The power generated would be 0.005 percent of the net capacity of all of Alberta Utilities facilities, 2.9 percent of the net capacity of Edmonton Power's Rossdale and Clover Bar facilities,[53] and 93.8 percent of the capacity of the Proctor and Gamble Ltd. plant in Grande Prairie.[54] Explanations for the apparent differences in the amount of power that could be generated in Edmonton compared to other parts of the world were not evident in the literature reviewed.

Alternatives to Incineration

Refuse-Derived Fuel

One way for a municipal authority to circumvent problems associated with disposal of refuse is to process the incinerable portion of the waste stream and sell it as fuel to industrial or other users. The technical problems of burning refuse-derived fuel are shifted from the authority to industry, and the problem for the authority becomes largely one of marketing the fuel.

Shredded refuse is sometimes difficult to market because with its low density (about 300 kg/m^3) it is costly to transport.[55] The high cost of transporting shredded paper can be partly surmounted by compressing the fuel, which makes it more difficult to feed the furnaces,[43] or by molding the shredded paper into pellets.[56, 23] Another advantage of pellets is that when produced in the same size range as coal they can be fed into the combustion chamber with the coal, thereby eliminating the need for the separate feeding systems that are requisite to the use of "fluff" refuse-derived fuel; that is, finely shredded paper.

One problem to which particular attention must be paid is the moisture content of refuse-derived fuel. Because of moisture, paper and cardboard will not store for any length of time without deteriorating.[55] The resulting change in physical condition can make pneumatic stoking (that is, using air pressure to stoke the furnace) difficult.[55] Pellets, for instance, must have a moisture content between 17 and 23 percent (wet basis) "as below 17 percent the pellets crumble and above 23 percent they decompose during storage".[57] Production of refuse-derived fuels at the

user's premises might minimize the storage problem for the authority, but except for users requiring large quantities of refuse-derived fuel, the cost of constructing the equipment needed to process the refuse into fuel may be prohibitive for the user.

Negative environmental aspects of refuse-derived fuel plants may include high concentrations of bacteria and trace metals. Fiscus et al.[58] investigated air quality at various waste handling facilities, including the St. Louis-Union Electric refuse-derived fuel plant in St. Louis, Missouri. They found generally higher ambient counts of bacteria (total bacteria, total coliform, fecal coliform, and fecal streptococci) airborne on particulate matter at the refuse-derived fuel plant than at an incinerator, a waste transfer station, a waste water treatment plant, and a sanitary landfill;[59, 60] the measurements of bacteria were taken within the facility itself and upwind and downwind at the property lines of the facility. Bacteria counts at the landfill were often significantly lower than at the refuse-derived fuel plant.[60] Fiscus et al., however, conceded that it was difficult to assess the significance of the higher bacteria levels at the refuse-derived fuel plant because:

1) There is insufficient information, data, or relevant standards to determine the levels of bacteria that might be hazardous.[59]

2) The upwind levels of bacteria were also highest at the processing plant, which makes it more difficult to conclude that the processing plant has the greatest effect on downwind bacteria levels.[60,61]

Significant increases in the downwind concentration of trace elements at the refuse-derived fuel plant and the waste transfer station were also evident.[62] As with the bacteria counts, the significance of the higher concentrations of trace elements was difficult to assess because there were no ambient air standards for most of the trace elements.[63] Filter systems applied to the main sources of dust emission can significantly reduce particulate and bacteria concentrations.[59]

Recycling

Resource recovery is almost always a component of waste treatment schemes that attempt to minimize the use of sanitary landfills. Although recycling is sometimes difficult, most of the recovered materials can be used again. Recycling and incineration are, however, competitors for paper.[64, 65] Since it is likely that the energy recovered by incinerating may be less than the energy saved by recycling,[66] focusing on means to better facilitate recycling may be desirable.

Since it is likely that more energy is saved by recycling than is recovered by incinerating, focusing on means to better facilitate recycling may be desirable.

There is, for instance, opposition to a proposed steam-generating plant in Ottawa on the grounds that recycling programs in the area would be hindered.[67] There are, however, several difficulties with programs to recycle paper. Some of these are:

1) Most pulp mills tend to be located near the timber source rather than near cities where the waste is generated. There are, therefore, often large transportation costs associated with paper recycling.[68]

2) More machinery is usually required to handle secondary pulp, so there are extra machinery costs involved with paper recycling.[68]

3) Different kinds of paper must be kept separate in order to make best use of the paper when recycling.[68, 69]

4) The market for recycled paper has tended to be unstable.

Such difficulties may make incineration of paper a more feasible solution to waste management than recycling, even though in the long run recycling of paper may be more desirable.

Economics of Waste Treatment - Some Considerations

Marketing

Prior to committing capital to various of the alternatives to landfilling, careful attention must be paid to marketing recovered resources such as metals, heat, and refuse-derived fuels. For incineration or for recycling, superficial market studies are not sufficient.[70] What is required is a detailed study of local industries "to identify a number of potential markets and determine the specifications, quantities, and price each would set for recovered products".[70] The markets must be secured before capital is committed to resource recovery facilities.[48] Also, more attention could be paid to promotion of markets for recovered products,[71] including promotional efforts to ensure that primary metals and fuels do not have unfair advantages over recovered resources.[71] Without markets to use recovered resources there is no income to offset the greater costs of resource recovery facilities, making alternatives to landfilling less feasible.

Aspects of Costing of Waste Treatment

Resource recovery has greater capital and operating expenses than landfilling,[72] and the greater the degree of upgrading of the resources the greater are these expenses.[14] Offsetting the greater costs are savings in conventional fuels, savings in landfill costs, and income from sale of recovered material;[73] there may be some social and environmental cost savings associated with resource recovery, but they are not typically, nor easily, incorporated into conventional cost analyses. Another advantage of resource recovery is that upgraded resources (for example, steam or electricity) are usually easier to market[14, 74] and higher prices can be commanded for them (though the upgraded resources are not necessarily more profitable).

One of the most important determinants of ability to market recovered fuel resources is price in relation to conventional fuels.[74] Using refuse-derived fuel as an example, several different ways of pricing fuel could work, or have worked under different circumstances. All characteristics of the refuse-derived fuel (such as physical form, ash content, and sulphur content) can play a role in determining the price, but heating value and shipping distance are often overriding considerations.[75] One possibility is pricing refuse-derived fuel on a calorific value basis. For example, if the calorific value of the refuse-derived fuel was half that of coal, then it may be priced at one half the value of coal. A market edge could be given the refuse-derived fuel by pricing it somewhat lower, on a calorific value basis, than competing or complementary fuels.[76] In some cases the discount may have to be great enough to pay for the extra costs the buyer incurs for converting boilers, and associated increases in operating costs. Where, however, a local authority is incinerating the refuse-derived fuel, the refuse-derived fuel can be credited with the full value of the conventional fuel replaced,[76, 41] because no market edge would be necessary.

While the price received for the recovered resources strongly affects the feasibility of disposing of solid wastes by other than landfilling, the feasibility of alternative disposal methods can be improved by levying a dumping charge on refuse haulers where the costs of municipal solid waste disposal are traditionally covered by municipal revenues.[77, 78, 79] Alternative means of waste disposal may also become more feasible if hitherto unaccounted for intangible benefits (for example, social and environmental benefits) of using refuse-derived fuels are introduced into cost analyses.

To date, low fuel costs and low landfill costs have made refuse-derived fuels economically unattractive.

To date, low fuel costs and low landfill costs have made refuse-derived fuels economically unattractive.[80] But such conditions which favor landfilling over alternative disposal methods may not persist. It is likely that the price of oil will increase in the years ahead and increases in the price of oil will be mirrored by the price of coal.[81] Rising fuel costs would improve the economic attractiveness of refuse-derived fuels, especially if the cost of refuse-derived fuels were to rise at a slower rate than conventional fuels. The costs

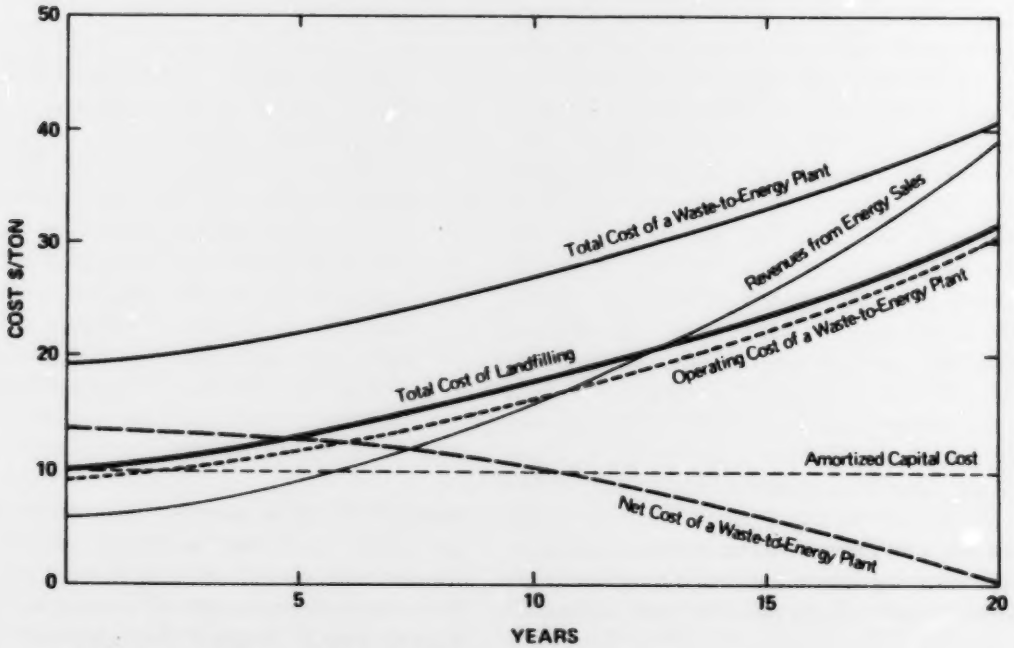
of landfilling will also increase if environmental constraints regarding landfills become more stringent, and as new landfill sites are increasingly distant from the waste generators. The resultant increased costs of landfilling would improve the economic feasibility of resource recovery. The greater transportation costs would make landfilling less attractive, and the requisite refuse transfer stations* would facilitate resource recovery,[82] but are the serious cost disadvantages associated with transfer stations[83] going to be experienced before the economic merits of resource recovery facilities are recognized?

The cost of capital strongly affects the feasibility of alternatives to sanitary landfilling. High discount rates tend to favor the use of landfill sites while low discount rates improve the feasibility of resource recovery.[86] Decisions on the feasibility of alternatives to landfilling depend upon the general economic climate at the time the decision is being made and upon the means by which the proponent raises the capital for such ventures.

* A refuse transfer station is a facility where garbage from local areas is accumulated prior to transfer to a landfill site.

If increases in the value of energy and in the capital costs of new plants and equipment can be expected, then investments made now in energy recovery may be financially warranted.[85] Figure 1 illustrates that wherever the revenue received for the energy is increasing at a rate faster than both the total plant costs and the costs of landfilling, converting waste to energy is likely to become cheaper than landfilling. One important feature of Figure 1 is the horizontal line depicting the amortized capital costs. Once made, an investment is paid back in level installments while other costs increase. But the two lines critical for the interpretation of the graph are first, that depicting the net costs (operating costs and amortized capital costs minus revenues from energy sales) of a waste-to-energy facility, which decreases with time due to the relatively rapid rise in revenues from energy sales, and second, the costs of landfilling, which rise over time. Although the net costs of a waste-to-energy plant are initially greater than the costs of landfilling, in Figure 1 after five years the costs are the same, and thereafter for the lifetime of the plant the net costs for the waste-to-energy facility are less than those for the landfill.

Figure 1. Feasibility of Investment in Energy Recovery



SOURCE: After Abert and Alter 1979:193

Notes: Total cost of a waste-to-energy plant = operating cost plus amortized capital cost.
Net cost of a waste-to-energy plant = total cost minus revenues from energy sales.

The cumulative net costs of a waste-to-energy plant are the same as those for landfilling after about eight years; accounting for the opportunity costs of the waste-to-energy facility would move the break-even point back further yet. The trends shown in Figure 1, and the conclusions that can be drawn from them, however, may not be applicable in all locations at all times. Assessment of the feasibility of energy recovery in any particular location depends upon the relationship between local costs of a waste-to-energy plant, local costs of landfilling, and revenues from energy sales.

Comparison of Waste Treatment Methods

A general case study of the costs of waste disposal and resource recovery was described by Wilson.[84] The case study was based on a number of conventions that were designed to overcome the problem of results of economic analyses differing according to the approach or the assumptions used in the analyses. A particularly interesting feature of Wilson's approach was the ranking of various disposal and resource recovery techniques while taking into account uncertainties in the results.

Wilson ranked 30 disposal options, shown in the first column of Table 2, based on the average of discounted net present costs (the deterministic base case analysis) and a probabilistic distribution of discounted net present costs (risk analysis). Wilson[87] determined that the options may be divided roughly into two groups, a lower group (ranks 1 to 11) having discounted costs less than 15 pounds sterling per metric ton, and an upper group (ranks 12 to 30) costing more than 20 pounds sterling per metric ton. In the lower group of options were contained all the landfill-based options and five refuse-derived fuel options.[87] Options producing electricity or heat were in the higher cost group, and of the options producing steam or electricity, incineration of untreated waste was the cheapest.[88] In all of the options that Wilson analyzed, only magnetic metals were recovered from the inorganic fraction. Additional materials recovery would increase the net additional costs and currently would be uneconomic.[88]

The remaining four columns of Table 2, the results of sensitivity analysis, show the effect on the rankings when four inputs different from those used in the deterministic base case are analyzed. The four inputs and the degree to which they differed from the original assumption are:

1) Plant utilization was 100 percent; that is, the waste disposal plant was in continuous operation at 100 percent of design capacity. In the base case analysis the plants were assumed to have a design capacity of 400 metric tons per day, but were operating at 300 ± 40 metric tons per day. In addition, the following operating schedules were assumed in the base case: a) for landfilling one shift only for five days a week, b) for waste separation plants, two shifts for five days a week, c) for non-recuperative incineration options, three shifts for five days a week, and d) for all the high temperature energy-recovery processes, continuously. Wilson[89] concluded that systematic increases in plant utilization make resource recovery operations more competitive by decreasing the cost per metric ton.

2) Energy revenues were twice those assumed in the base case analysis. Revenues twice those assumed in the base case were generally above the then-current levels for conventional energy.[89]

3) Discount rates of 5 and 25 percent. A discount rate of 10 percent was assumed in the original discounted cash flow model.

4) Waste throughputs of 150 and 1,200 metric tons per day. Throughputs of 300 ± 40 metric tons per day were assumed in the original analysis. (In its own analysis of some resource recovery options the City of Edmonton assumed a 1,365 metric tons per day capacity, so presumably the throughput would be similar to the high throughput that Wilson analyzed. The results of Edmonton's studies are described later in this report).

Wilson[90, 91] found that the four inputs (but not only the above four) had significant effects on the net present costs and the ranking of the disposal methods. The demonstrated sensitivity of cost estimates to various inputs suggests that conclusions about the economics of waste disposal options should be framed by the inputs that were used in the analyses.

Table 2. Economic Ranking of Waste Disposal and Resource Recovery Options

Conditions / Options	Option Ranks: deterministic base case (and means from risk analysis)	Option Ranks: risk analysis 90% confidence level	Option Ranks: risk analysis ranges	Sensitivity Analysis: plant utilization 100%	Sensitivity Analysis: revenues twice base level	Sensitivity Analysis: discount rate 5%	Sensitivity Analysis: discount rate 25%	Sensitivity Analysis: waste throughput 150 tpd	Sensitivity Analysis: waste throughput 1200 tpd
Landfill	1	1	1-3	2	2	2	1	1	2
Landfill with									
transfer to road	5	5	3-8	6	7	=5††	5	5	6
transfer to rail	8	9	4-12	11	10	=8	7	8	9
pulverization									
1 shift	6	6	3-11	5	6	=5	6	6	5
2 shift	4	4	2-8	4	4	4	4	4	4
baling	9	8	6-12	9	=11	=8	9	9	10
Incineration									
non-recuperative	13	14	10-25	15	21	13	14	=13	19
steam generation	15	17	10-28	13	13	14	18	15	20
electricity generation	19	20	10-28	14	14	16	22	=17	23
modular	14	13	10-25	19	24	15	12	12	22
modular and steam	20	19	11-28	16	15	=19	21	16	26
Composting	16	15	11-27	18	20	=17	=15	21	16
RDF* as a supplementary fuel									
American RDF	10	10	6-16	8	8	=8	10	11	8
powder RDF	18	18	11-28	20	18	=19	17	20	13
paper-based RDF	7	7	3-11	7	6	7	8	7	7
pulverized fuel									
Case a**	2	2	1-4	1	1	1	2	2	1
Case b†	3	3	1-7	3	3	3	3	3	3
Direct Firing of RDF									
suspension firing	23	24	12-29	23	22	23	24	22	25
incinerator turbine	21	21	11-28	17	16	21	20	19	21
Wet pulping with									
fibre recovery	26	26	15-29	27	28	27	26	24	27
incineration & electricity	27	27	15-30	26	27	26	=28	=25	28
fibre and wet RDF	12	12	8-24	12	=11	12	=13	=13	14
wet RDF	11	11	6-21	10	9	11	11	10	11
dried RDF	17	16	11-27	21	17	=17	=15	=17	=17
Pyrolysis									
Occidental	22	22	12-28	22	19	22	19	23	12
Union Carbide Purox	30	30	27-30	30	30	30	30	30	30
Carborundum Torrax	24	23	12-29	24	26	24	23	=25	=17
Monsanto Landgard	25	25	13-29	25	25	25	25	27	15
Acid hydrolysis	28	28	17-30	28	23	28	27	28	24
Anaerobic digestion	29	29	23-30	29	29	29	29	29	29

Source: Wilson 1979:280, 281

* RDF – refuse-derived fuel
** Case a – Wilson assumes an optimistic energy-specific price (cost per unit of heat) 40 percent of that for coal (1979:293).
† Case b – the user pays transport costs; that is, the net price of disposal is zero, plus Case a (Wilson 1979:293).
†† = – ties in rank

While careful economic analysis (including the effect of estimated revenue ranges, capacity utilization, taxes, transportation, disposal charges, and so on[92] is necessary in order to assess the feasibility of various means of disposing of solid wastes, costs alone may not be the criteria for deciding on a means of disposal. Lowest cost solutions are not necessarily the most politically[93] nor environmentally acceptable ones. Although landfilling is a low-cost means of refuse disposal, many people perceive landfills negatively, whereas resource recovery plants are often viewed positively.[39] Decisions on solid waste treatment options will probably be based on many considerations, notwithstanding the importance of economics.

Continental Europe in Contrast to North America

Under present circumstances disposal of solid wastes by means other than landfilling is often not economically attractive. Despite economic unattractiveness, energy recovery from waste is much more common in places such as Europe and Japan than in North America. There are a number of reasons for this, including:

1) Waste-to-energy plants in Europe are substantially subsidized by central government grants.[94]

2) Because the plants are heavily subsidized, local authorities are not under such pressures to accept the lowest tenders,[94] nor are they as constrained as in North America to achieve economies of scale.[95] But the up-front cost of larger, scale-efficient plants diminishes the attractiveness of resource recovery in North America. A modular approach to increasing plant capacity; that is, one where smaller increments of capacity are added as needed, which does not offer the economies of scale that large plants do,[95, 96] may be one way of mitigating this obstacle to resource recovery. The modular approach, for instance, appears to be working satisfactorily for a 108 ton-per-day waste-to-energy co-operative in New Hampshire.[97]

3) In some European countries there is a shortage of land, so there is a strong incentive to minimize the amount of land used for landfilling.[98]

4) District heating is more prevalent in Europe than in North America, so there are many more opportunities for waste-to-energy schemes to be operative. Where district heating is prevalent in North America, it often involves educational institutions or government buildings rather than high-density residential buildings. The latter offer better potential for waste-to-energy programs than institutional buildings because there is a greater number of high-density residential buildings[98] with longer periods of utilization.

5) Coal and other fossil fuels are much more expensive in Europe than in North America, thereby tending to tip the economic analyses in favor of recovery of energy in Europe.

6) In many areas of Europe "electricity generation is a municipal function rather than a national one"[99] so that relatively small amounts of refuse-based energy are significant to the municipalities concerned.[99] The same amount of electric energy would be of less interest to larger utilities. In Alberta, however, the Energy Resources Conservation Board may require electricity generated by a waste-to-energy plant to be connected to an electric distribution system and may require a larger utility company to buy the electricity (Hydro and Electric Energy Act RSA 1980 cH-13 s17(2)).

The City of Edmonton's Arguments For Landfill

Recently the City of Edmonton briefly examined the economics of various means of disposing of municipal wastes. In one study by Edmonton Power and Edmonton Water and Sanitation,[100] the costs of landfilling were compared with two alternatives: co-generation where mass incineration of solid waste produced steam for power generation and district heating, and incineration of solid waste to produce steam suitable for power generation. The total present net annual costs for each method of disposal were compared. The economic comperisons were biased in favor of energy recovery by assuming minimum

operating and maintenance costs for the alternative systems. The authors also assumed that energy recovery operations would be located at Clover Bar; energy recovery at sites more distant from Edmonton, such as at Genessee, would be more expensive.

A recent City of Edmonton study concluded that the use of solid wastes as fuel for power and/or steam production is not economical.

The study concluded that the use of solid waste as fuel for power and/or steam production is not economical. The total net present value of landfilling in 1982 dollars was 42.3 million dollars; of incineration to produce steam for power generation and district heating, 126.7 million dollars; and of incineration to produce steam suitable for power generation, 83.3 million dollars. The very high cost of incineration for power generation and district heating was in part due to the absence of a distribution system for steam in Edmonton. Sensitivity analyses suggested that incinerating solid waste for power and/or steam production may be economically viable if for the first alternative (steam production for power generation and district heating) landfill costs were seven times present cost, gas prices were 2.5 times current forecast values, or steam were sold for 2.25 times the current forecast values for gas, and if for the second alternative (steam production to generate electric power) landfill costs were four times the present cost or gas prices were about 1.75 times current forecast values. Neehall[9] estimated that the economics would not begin to favor an alternative to landfilling for another 10 years.

The City also examined the economic feasibility of using municipal solid waste for co-generation of power at the Genessee thermal plant. Co-generation at Genessee was also considered to be uneconomical. The additional costs that were identified were 41 million dollars for the capital cost and 12 million dollars annually for the operational costs of a facility to manufacture refuse-derived fuel, 10 million dollars for boiler modifications, hauling, and storage systems, and one million dollars annually for operating and maintenance costs at the thermal plant. Another rationale for rejecting the use of municipal solid waste for power generation was that the refuse-derived fuel which could be produced by Edmonton's waste stream would not be sufficient to fire one of the 375 megawatt units to be installed at Genessee. The value of this argument, however, seems questionable since it is possible to incinerate refuse-derived fuel simultaneously with coal, with technological and environmental advantages that were previously discussed.

Other arguments forwarded by the City also militate against the use of alternative disposal systems. One is that landfilling is necessary regardless of whether or not energy is recovered from the solid waste, and if there were energy recovery systems Edmonton's landfill requirements would be reduced by a maximum of 30 percent.[9] The savings, in money and environmental benefits, of alternative disposal methods would therefore be limited. Furthermore, another disposal method to accommodate energy recovery may not be necessary if sufficient quantities of methane generated by decomposing solid wastes can be tapped. A consultant's study on the use of methane generated in Edmonton's landfills is expected by Edmonton Water and Sanitation in the spring of 1983. Another argument is that before refuse-derived fuel can be manufactured there must be material recovered from the waste stream. There is no market in the area for materials such as metal and glass which could be recovered. Therefore economic benefits of recovering materials from the waste stream in order to offset the cost of energy recovery are not presently possible in Edmonton. The existence of such circumstances may only be transitory – for example, the rubble content of Edmonton's waste stream may not be so high once major redevelopment in the city slows down, or a market for recycled metals and glass could develop – so that alternatives to landfilling may appear more feasible in the near future.

The City of Edmonton's arguments against alternative disposal methods are economic arguments. The strength of those economic arguments might be reduced if some changes in the means by which the costs of disposal are recovered by the City were made. The City's philosophy regarding funding of waste disposal is that, first, a basic necessity such as proper waste disposal should be provided on a revenues-equal-costs basis and, second, since proper

waste disposal is a service to the community that benefits everyone either directly or indirectly, most of the revenue for solid waste disposal should come from general taxation. Furthermore, each disposal method must be a separately financed entity; for example, if there were an incinerator operating in conjunction with a landfill, the incinerator and landfill would have to be separately financed. The premises that *revenues should equal costs* and that *disposal systems should be separately financed* preclude subsidization of an auxiliary disposal system by landfilling operations. Generation of most of the revenue for solid waste disposal by general taxation makes the collection of additional revenue from generators of larger quantities of waste (commercial and industrial users) awkward to justify. Through their taxes, commercial and industrial users already subsidize domestic waste disposal, so collecting additional revenues from them would seem like double taxation. A self-supported system – that is, a utility system – would be better suited to varying the disposal charge according to the type of waste generated and in increasing proportion to the amount of waste generated. Edmonton Water and Sanitation has recently reviewed the prospect of changing from a tax-supported to a self-supported solid waste disposal system. Edmonton's City Council has decided that the tax-supported system should remain in place.

Alberta's Waste Management Assistance Program

In 1978 the Government of Alberta approved the Waste Management Assistance Program to promote environmentally sound solid waste management throughout the province. One of the main thrusts of the program was "to encourage regional sanitary landfill operation by providing land, initial capital improvements and major operating equipment".[101] To date, eight regional landfills which handle refuse from a large portion of rural central and southern Alberta have been funded at an annual cost of approximately three million dollars.

A recent modification of the program proposes that funds for the capital costs for an incinerator be available to regional waste management authorities in rural areas where suitable land is not available for sanitary landfill operations. However, the economics of incineration in Alberta are uncertain, so for now funding will be available only for one experimental incineration facility. The capital costs for the incineration facility and three years' operating costs in excess of normal sanitary landfill operations will be covered by the government. The site for an experimental incinerator has not yet been determined.

The initiatives established by Alberta's Waste Management Assistance Program may have been set back by more recent changes to regulations under the Public Health Act. The new regulations are less stringent than were the previous ones. The new regulations permit:

1) Landfills serving populations up to 10,000 to be classified as modified landfills. (Modified landfills are subject to less stringent operating standards than are sanitary landfills.) Before the change, only landfills serving populations up to 5,000 could be classified as modified landfills.

2) Some burning of wastes at modified landfills. Previously, no burning was permitted.

Because the new regulations are less stringent, the incentive for rural municipalities to use regional landfills and, potentially, incineration for solid waste disposal has probably decreased.

Conclusions

In North America landfilling is a common method of disposing of municipal wastes. However, environmental concerns and, to a lesser degree, economic concerns dictate that waste management authorities examine alternatives to landfilling.

A few alternatives to landfilling were briefly examined in this review; most of the alternatives examined were variations of incineration. Each alternative appears to have unique technological, environmental, and economic advantages and disadvantages. No one alternative is best in all cases. Disposal methods which are more common in Europe, for instance, are not always suitable in North America because different circumstances (for example, economic, social, and so on) exist in Europe and in

North America. The best disposal alternative for any one area is likely to be determined by the area's objectives and resources, which must be carefully assessed before decisions to implement disposal alternatives are made.

Economics appears to be the pivotal issue when deciding on methods of disposing of municipal wastes. Currently most of the alternatives are more costly than landfilling, though such conclusions may not always be based on a long-term or a broad outlook, for example, an outlook which evaluates the economics of environmental concerns. Recent analysis suggests that incineration of municipal wastes to generate electric power is far more expensive than landfilling, but that manufacturing refuse-derived fuels from municipal wastes may be only slightly more expensive. Because some alternatives are cost-comparable to landfilling, they can no longer be dismissed out-of-hand as unsuitable. Especially when the costs of alternatives are nearly comparable, other issues, such as environmental issues, may replace economics as the pivotal issue in decisions regarding municipal waste disposal methods.

The brief literature review conducted for this paper did not give a definitive answer about which disposal alternative is best for Edmonton. Information from the City of Edmonton is, however, in general agreement with many of the conclusions found in the literature; that is, sanitary landfilling is the cheapest disposal alternative for the present. Economics appear to be the key issue for the City in its decisions on disposal methods. The City of Edmonton has concluded that, given present trends, alternatives to sanitary landfilling will not be cost effective for another 10 years. The conclusions did not, however, appear to be based on a thorough analysis of the problem. For instance, the conclusions of the City of Edmonton's study might have been more appropriately described in probabilistic, rather than deterministic, terms.

A better assessment of the feasibility of alternatives would result if a more detailed cost analysis of alternative methods of processing Edmonton's solid wastes were conducted; it is the intent of the City of Edmonton Water and Sanitation Department to recommend that a detailed analysis of the feasibility of incineration be done by 1990. In view of the Government of Alberta's recent expression of willingness to fund an alternative to landfills, subsidization of alternative means of waste disposal similar to that which the government has extended to rural municipalities in Alberta could be investigated in such a cost study.

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